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Quantitative Evaluation for Transportation System Application
— The model for induced travel demand forecasting

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Abstract

At present, many kinds of new transportation sytems have being developed and partially realized as the practical urban traffic systems in Japan. But, these developments don't be contributed to the solution of several urban traffic problems. Therefore, this research and study that aim to grasp the characteristics and the adaptability of new transportation systems and to evaluate the suitableness of these systems' applications quantitively have been started. The way of the investigation is to start of extracting new urban transportation systems as the subject of study and to research the specific values of these systems according to the evaluation sheets. On basis of research results the characteristics values of the systems are represented graphically. We show the evaluation of suitablenass of transportation systems' application to the model routes by the radar chart and AHP. Moreover, using the same technologies, changes in traffic demand and in the transportation share ratio are calculated when a new system is introduced into a region already being served by other systems.

Key Words: AHP, Traffic plan, Transport demand, Radar chart, New transport system

1. Introduction

To cope with an increasing diversification of transportation services, new urban transportation systems are being developed and steadily they are coming into practical service, but quantitative discussions done are a few about what routes are suitable for such systems.

In this paper the features of such systems are quantitatively evaluated in comparison with the existing means such as bus or subway. To be more specific, here are illustrated several cases in which adaptabilities of such systems for model routes are evaluated utilizing radar chart and AHP (Analytic Hierarchy Process). Meanwhile, using the same technologies, changes in traffic demand and in the transport share ratio are calculated assuming the case when a new transportation system is introduced into a region already being served by other systems.

2. Adaptability Evaluation of a New Transportation System

2.1 Selection of items to be studied

Before embarking on the study, major items are first selected from the standpoints of users, operators and society and they are divided into medium and minor to facilitate the quantification work, the finalized items being listed in Table 1.

Then for each medium item, each new system is assigned a score. In the scoring work the new system is ranked in terms of its rating as superior, equivalent or inferior referring to the existing bus or subway.

2.2 Selection of model route and object system

A specific route is picked up for quantitative evaluation of the new system's adaptability. Then a system likely to be adaptable to the selected route is put to quantitative evaluation. In Table 2 the model routes and the object systems are described. In this Table, (1) - (4) are characterized as follows ; (1) is a rope-driven levitation system ; (2) is an iron-wheel supported, on-board primary system utilizing the on-board linear motor for propulsion ; (3) is a wheel-supported ground primary system with the linear motor distributed on the ground ; and (4) is a linear motor-propelled, electromagnet-supported and guided, on-board primary magnetic levitation system, which has been identified on the test track of Nagoya as a practical phase.

Table 2 Outline of model route and object transport system

	Total extension	station interval	minmum curvature	maximum gradient	object system
A	200 m	------	tangent	flat	new transport, OTIS variable-speed mobile walk
B	5 km	800 m	100 m	5	new transport, LRT, sky-train bus, WEDway P.M.
C	10 km	800 m	100 m	5	bus, new transport, magnetic levitation system

(1)rope-driven levitation system
(2)iron-wheel supported, on-board primary system utilizing the on-board linear motor forpropulsion
(3)wheel-supported ground primary system with the linear motor distributed on the ground
(4)linear motor-propelled, electromagnet-supported and guided, on-board primary magnetic levitation system, which has been identified on the test track of Nagoya

3. Attempt at quantification of adaptability evaluation

3.1 Trial of radar chart technology

Under assumption of introducing an object system on a model route, the medium items are scored by the method 2.1. The sum of their scores is assigned for each major item. The radar charts with 7 shafts each representing one major item are illustrated in Figs. 1 and 2.

Table 1 Evaluation items for adaptability of transport systems

Viewpoints	Items(major)	Items(medium)	Items(minor)
Users	Travel time short	high speed frequency pductuality	schedule speed, max.speed, acceleration-deceleration, minimum run time, track exclusive or joint use, weatherproof
	Easy to get on/off and to change	access to station easy to get on/off easy to change	station interval height from ground to ride level, doors, etc, single or plural, possible to interconnect
	Fast speed	ride comfort interior space wide interior equipment sense of security	vibrational acceleration, jerk, internal noise car dimensions, passenger capacity, seating capacity, convenience of airconditioning, sealability, guarantee of security, traffic accident
Operator	Response to traffic demand	transport capacity, control of transport capacity, freedom of route	max.transport capacity, train capacity, schedule speed, control of transport capacity, immediate response, drive system, elevated, ground, line length, sectional space
	Easy to introduce	space to introduce infra cost extra infra cost phased construction easy or hard	radius of curvature, exclusive track, structural integration, sectional space, construction gauge, rolling stock gauge wayside facility, rolling stock, extension, expansion of transport capacity, underground, elevation,
	Easy to operate	operating personnel energy consumption maintenance cost reliability response to emergency	automated degre, operating power consumption, maintenance-free degree, storage cost, post-contact repair, operational efficiency, response to potential fault, evacuation, guiding
Social significance	Good environment	low noise low vibration exhaust gas	external noise ground vibration exhaust gas level
	landscape	landscape	

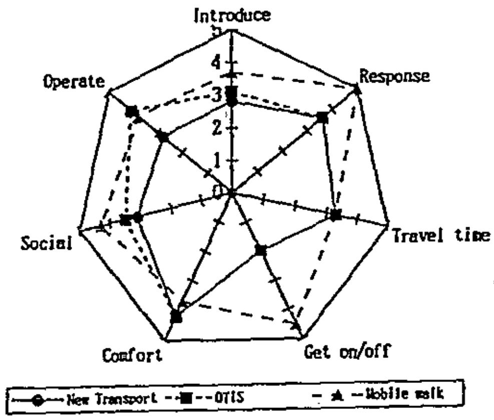

Fig. 1 Radar chart for system adaptability(Model A)

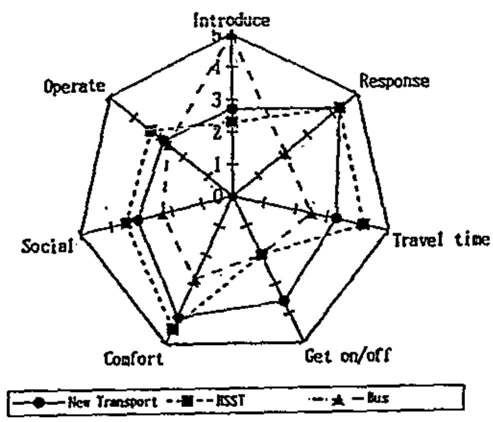

Fig. 2 Radar chart for system adaptability(Model C)

On these charts, the shaft located above the horizontal line indicates an item for the system whose scoring changes depending on the model route selected, while the shaft located below the horizontal line indicates one for the system whose scoring is invariable and specific to the system.

Model route A in Fig 1, being short as a whole, is found more suitable for the mobile walk than for the vehicle system (OTIS, new transport), because it is easier to introduce and to get on/off or to change.

On the contrary, model route C in Fig.2, being long as a whole, is found more suitable for the magnetic levitation system (H-100) because of shorter travel time, ride comfort and social significance, but more suitable for the bus which is easier to introduce and more convenient to get on/off or to change. Thus a characteristic difference emerges between the vehicle system like the new transport of magnetic levitation system and the road-moving one like the bus.

3.2 Application of AHP

Whereas the radar chart evaluation of the transport system is multi-dimensional and its applicability to the model route cannot be decided definitely, AHP can uniquely determine the degree of priority for each system. AHP is applied hierarchically as illustrated in Fig.3.

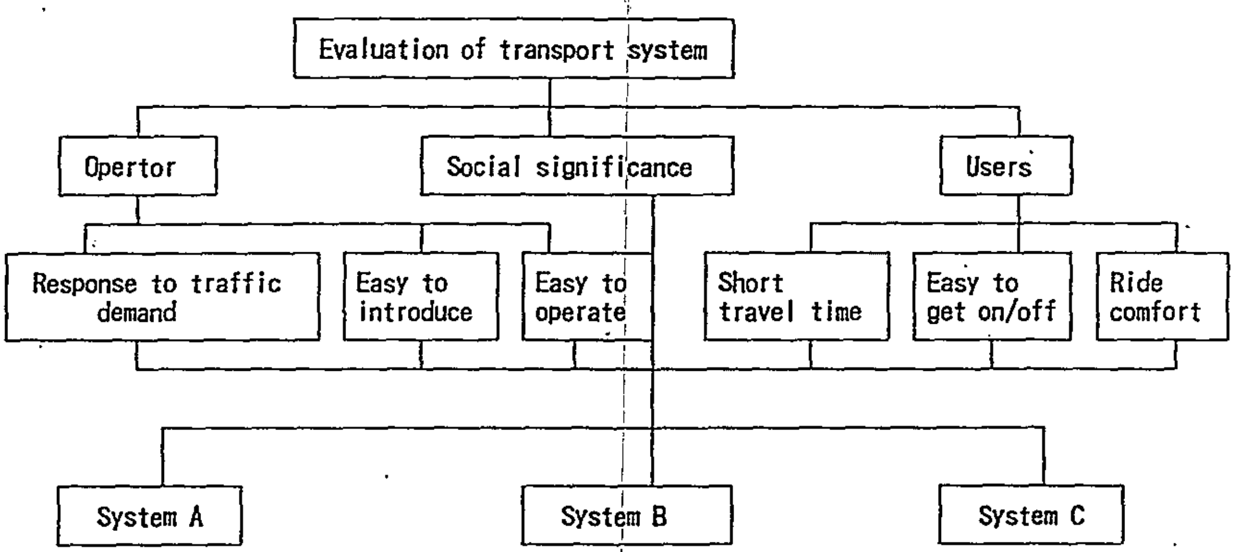

Fig.3 Hierarchical structure for evaluation of transport system adaptability

In the case of model B, the paired comparison matrix [Y] for each viewpoint and each item is formulated as shown in Table 3. In this case, each element Y_{ij} of [Y] = (1/16, 1/8, 1/4, 1/2, 1, 2, 4, 8, 16). Depending on the relative degree of importance when the item or viewpoint in the column is seen from the item or viewpoint in the row, the arrangement of the numerals changes like 16 - 8 - 4 - 2 - 1 - 1/2 - 1/4 - 1/8 - 1/16. In consequence, if the relative degree of importance for the row element is higher than that for the column element, the numerals become fractional.

Meanwhile, in quantification the ranking is done using geometric series so that it can more elaborately express the human senses.

Next, when the object systems are limited to the following three, i.e., the new transport, bus and LRT, they can be quantified for each item as shown in Table 4.

Table 3 Paired comparison matrix between viewpoints and items evaluated

	ope.	use.	soc.
operator	1	1/2	1/2
user	2	1	1
society	2	1	1

between viewpoints matrix Y1

	dem.	int.	ope.
demand	1	1/8	1/4
introduction	8	1	2
operation	4	1/2	1

between items evaluated matrix Y2

	tim.	get.	com.
time	1	8	2
get on/off	1/8	1	1/2
comfort	1/2	2	1

between items evaluated matrix Y3

Table 4 Scoring of each transport system for each item

	Operator			User			Sociality
	Demand	Introduction	Operator	Time	On/Off	Comfort	Sociality
New Transport	4.3	2.7	2.8	3.3	2.0	4.2	3.1
LRT	2.9	4.0	3.4	2.9	4.0	3.1	2.7
Bus	2.1	5.0	2.5	2.5	3.5	2.7	2.3

In this Table, each element is scored according to 2.1, namely taking the full mark of each major item as 5.

The degree of priority for each system is to be sought here employing each matrix.

First, the specific values (0.2, 0.4, 0.4)for Y 1 are to be sought. These values represent the relative priority for each evaluation viewpoint (operator, users, society). For this model route with a long extension, the social significance is given higher priority.

Next, the specific values ; Y2(0.077, 0.615, 0.308), Y3(0.643, 0.101, 0.255) for Y2 and Y3 are to be sought. These values represent the relative degrees of the items investigated, the values for Y2 indicate the relative priorities between the evaluation items of the operator (response to traffic demand, ease of introduction, ease of operation), while those for Y3 indicate the relative priorities between the evaluation items (shortness of travel time, easiness to get on/off, ride comfort) of the users. Social significance, being a single item, is assigned a value of unity. Now, multiplying the relative importance of each viewpoint by the specific value of each item, we formulate a matrix vector (X) = (0.015, 0.123, 0.062, 0.257, 0.040, 0.102, 0.400), which means the relative priority of the item investigated of the model route. From (D) composed of matrix vector (X) and the element in Table 4 the following is calculated

$$\begin{bmatrix} \text{New transtort} \\ \text{LRT} \\ \text{Bus} \end{bmatrix} = [\,D\,]\cdot[\,X\,] = \begin{bmatrix} 3.167 \\ 3.048 \\ 2.779 \end{bmatrix} = \begin{bmatrix} 0.352 \\ 0.339 \\ 0.309 \end{bmatrix} \quad \cdots (1)$$

the result indicating the relative priority of each system.

In this result, the relative priority for each system turns out as follows; new transport > LRT > bus.

Similarly, the results of evaluation with WED way people mover system instead of the bus (the items: travel time, get on/off, ride comfort, traffic demand, introduction, operation, social significance) scoring (0.257, 0.040, 0.102, 0.015, 0.123, 0.062, 0.040) turn out as follows ;

$$\begin{bmatrix} \text{New transtort} \\ \text{LRT} \\ \text{WED way} \end{bmatrix} = \begin{bmatrix} 3.167 \\ 3.048 \\ 2.337 \end{bmatrix} = \begin{bmatrix} 0.370 \\ 0.356 \\ 0.273 \end{bmatrix} \quad \cdots\cdots (2)$$

These findings are summarized in Fig.4,

Thus it is seen that the system generally judged unfit for long distance transport, like WED way people mover system, i.e., a ground primary system , is assigned a low priority, testifying that its adaptability to the model route can be quantitatively evaluated to a certain extent.

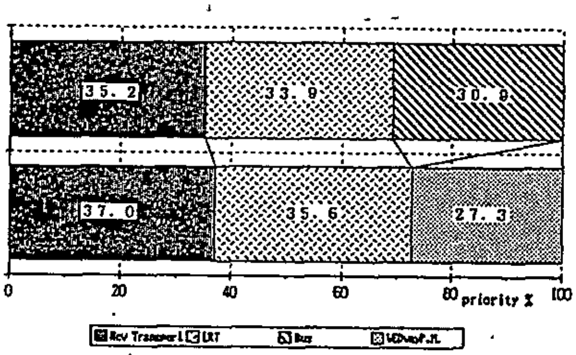

Fig.4 Calculated results of transport system priorities

It is confirmed that the relative priority of the transport system for model route can be quantified with aid of AHP. If the values thus obtained are regarded as the traffic demand on each transport system, it may be said that it is possible to calculate the total traffic demand and the transport share ratio on a model route.

It may also be possible to assume the values calculated by the equations (1) and (2) using the values in Table 4 as the traffic demand, but then the introduction of a new transport system will mean that the total traffic demand represents a simple addition of the transport volume by the new system to the existing transport volume ; in other words the new system introduced causes a simple increase in the total traffic demand (with no change in the transport volume by the existing system). Therefore, in this case instead of normalizing (giving the full mark 5) the system score for each main item, we resort to the method of normalizing the scoring of each medium item at the maximum for each item(that is, at unity). According to this method, whenever a new system is introduced, depending on the scoring of the new system we have to revise the scoring of the existing system, too.

4.2 Example of calculation.

In the case of model C assuming that the available transport systems are limited to the bus and personal cars, each evaluation item is normalized with maximum score given to each item and further each major item is normalized.

The results are given in Table 5 with each major item normalized.

Table 5 Scoring for formulation of traffic demand

	Operator			User			Sociality
	Demand	Introduction	Operator	Time	On/Off	Comfort	Sociality
Bus	0.584	0.875	0.5	0.494	0.667	0.667	0.458
Personal car	1.0	0.938	0.533	0.644	1.0	1.0	0.458

According to these results, the motor cars excel in all the items.

Moreover, when paired comparison matrices are set as in Table 6 between viewpoints and evaluation items, similar calculations to 3.2 wil determine the priorities of the systems. According to these calculations, the total traffic demand will amount to 1.292 with 0.557 going to the bus and 0.735 to personal cars. Now the changes in the traffic demand and in the transport share ratio when the new transport and the maglev system HSST are added to the existing route are to be calculated. Then the quantified volume for each system with the new transport added will turn out as listed in Table 7. Based on the above quantification the priorities given to respective transport systems will be like (4)

$$\begin{bmatrix} \text{Bus} \\ \text{Car} \\ \text{New Transport} \end{bmatrix} = \begin{bmatrix} 0.387 \\ 0.618 \\ 0.710 \end{bmatrix} = \begin{bmatrix} 0.226 \\ 0.360 \\ 0.414 \end{bmatrix} \quad \cdots\cdots (4)$$

Table 6 Paired comparison matrix between viewpoints and between evaluation items

	ope.	use.	soc.
operator	1	1/8	1/2
user	8	1	4
society	2	1/4	1

between viewpoints

	dem.	int.	ope.
demand	1	1/4	1/2
introduction	4	1	2
operation	2	1/2	1

between items evaluated

	tim.	get.	com.
time	1	8	2
get on/off	1/8	1	1/4
comfort	1/2	4	1

between items·evaluated

Table 7 Scoring for formulation of traffic demand

	Operator			User			Sociality
	Demand	Introduction	Operator	Time	On/Off	Comfort	Sociality
Bus	0.292	0.25	0.383	0.233	0.667	0.604	0.458
Personal car	1.0	0.25	0.767	0.467	1.0	1.0	0.458
New Transport	0.709	0.542	0.633	0.783	0.333	0.792	0.604

Here it is noted that the scores in Table 6 for the existing systems will turn out different, because with introduction of a new transport system the scores for the existing systems will also change relatively, for instance, the travel time turns out shorter.

Consequently, it is clear that the total demand increases about 33% to 1.715. The results after introduction of HSST are given in Fig.5. In this manner, it becomes possible by employing AHP to show the changes in the traffic demand and in the transport share ratio.

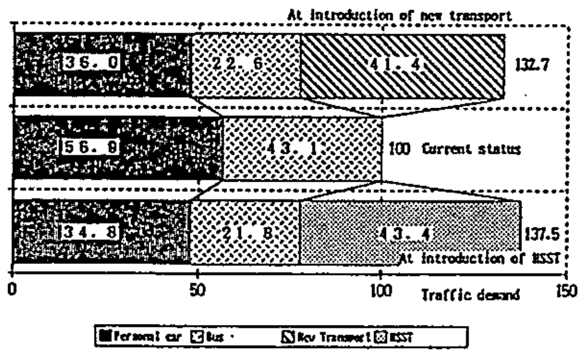

Fig5. Change in traffic demand at introduction of new system

5. Concluding Remark

As described above, an attempt was made at quantitative evaluation of the adaptability of a new transport system by scoring a new transport system, setting a model route and utilizing the radar chart and AHP. Besides, an example of employing AHP to calculate the change in traffic demand was cited.